(54) ELECTRICAL ENERGY METERS

This invention relates to electrical energy meters (usually kilowatt-hour meters) having a static or solid state measuring unit, and is particularly but not exclusively concerned with a meter for three-phase supply systems comprising voltage dividers and current transformers for level matching, a current supply, and an indicating device.

Known kilowatt-hour meters having static (solid state) measuring units as at present employed operate with analog signal processing methods, preferably based on the time-division method with subsequent current-frequency conversion. Such methods are unsuitable for an economical three-phase current meter, because with analog signal processing, accurate and hence costly component elements must be employed, which can additionally falsify measurement results by reason of their inconsistency in respect of time.

Energy supply organisations expect that a kilowatt-hour meter can be left in the supply system for many years without being checked and that such an appliance should remain operable for twenty to thirty years.

The invention is concerned with the provision of a generally improved meter.

According to the present invention, there is provided an electrical energy meter for metering an a.c. supply having one or more phases, the meter having a solid-state measuring unit which comprises:

a mutiplexer having inputs for receiving current- and voltage-proportional signals for the or each phase, a zero potential signal, and a reference potential signal, and arranged to output said signals successively;

an analog-digital converter connected to receive the multiplexer output and arranged to output the same in digital form; and

a digital computer arranged to control operation of the multiplexer, to receive the output of the converter, and to perform the following operations:

calculation and storage of a zero-point error value from the zero-potential signal when received by the computer;

calculation and storage of a calibration error value from the reference potential signal when received by the computer;

compensation of each received said current- and voltage-proportional signal for said error values;

for the or each phase, storage of a succession of values of at least one of said current- and voltage-proportional signals for that phase, as successively sampled by the multiplexer, and interpolation within or extrapolation from said succession of values to compensate for relative time displacement between sampling instants of the current-and voltage-proportional signals;

for the or each phase, calculating from the error value compensated current and voltage-proportional signals the instantaneous power for that phase; and

providing an output signal representative of energy consumption from said supply.

The computer may typically be a minicomputer.

For a better understanding of the invention and to show how the same may be

carried into effect, reference will now be made, by way of example, to the
accompanying diagrammatic drawings, in which:
    Figure 1 illustrates a meter employing a two-channel multiplex system;
    Figure 2 illustrates a meter employing a single-channel multiplex system;
    Figure 3 illustrates a meter employing a single-channel multiplex system in
which all the input quantities are present as current signals;
    Figure 4 are waveform diagrams illustrating signal sampling possibilities for
calculating instantaneous power; and
    Figure 5 illustrates a sampling sequence of a voltage and of a current for the
formation of an instantaneous power.
    Since a digital computer can only process digital values, the three voltage-
current pairs of the three phases of a three-phase supply system must be converted
into corresponding digital values. It must here be borne in mind that, for
determining the active power, the time relationship of the voltage of and of the
current of a phase must be maintained. For conforming to preset error limits, at
most one error of a few minutes of angle must occur; this corresponds to a time
error of a few microseconds at 50 Hz.
    If two analog-digital converters and one two-channel multiplexer are
employed, a time error can be avoided at additional cost (Figure 1).
    Advantageously, however, there are employed an analog-digital converter and
a single-channel multiplexer initially having six inputs. In this case, for example, the
six quantities to be measured are applied to the analog-digital converter in the
following sequence by the multiplexer and thereafter converted into digital values
and applied to a digital computer for further processing:

$$U_R - I_R - U_S - I_S - U_T - I_T$$

    Between the sampling instant, for example of the voltage U_R, and the sampling
instant of the associated current I_R, there occurs owing to the multiplexing a time
offset whose magnitude depends upon the muliplexing frequency.
    Since each quantity to be measured is sampled by the multiplexing, its value is
determined substantially from the harmonics which have still to be monitored.
Assuming that harmonics higher than the tenth play no part, a sampling frequency
of 1 kHz would be sufficient. Taking 2kHz, at least 16 kHz=60 μs are required,
including zeroising and calibration cycles. In this case, a time shift of 60 μs lies
between the sampling of a voltage and that of the associated current; in this way,
the measurement of the active power is already inadmissibly falsified.
    If the multiplexer, the analog-digital converter and the computer are so fast
that the multiplexing frequency can be raised to such an extent that the residual
time error is negligible, no further measures need be adopted. For the computer,
the multiplication of two numbers in a few microseconds constitutes a problem,
and this requirement can be met substantially only by parallel multiplication.
    This means that a fast computer must be employed, which does not involve
any increase in cost of the equipment. In the following, therefore, there will be
described a number of methods by which the time error occurring with slow
sampling can be substantially compensated for, so that it is possible to employ for
the processing of the measured value a computer having a substantially lower
output capacity.
    The first method involves the use of analog delay elements which are looped
into the supply conductors leading to the multiplexer at the three measurands
subsequently sampled in each instance. Starting from a numerical value of 60 μs as
assumed in the preceding example, such a delay is difficult to establish and to
maintain constant over long periods of time. At higher multiplexing frequencies,
when the time error is in any case already small, however, this method appears to
be entirely applicable for substantially compensating for this residual error.
    It is known from German Patent Application P 2537549.9 that the time error
which unavoidably occurs in single-channel multiplexing can be profitably used to
compensate for signal delays or angle errors which have arisen elsewhere in the
electronic meter, by ensuring that the sign and the magnitude of the two delays
cancel one another out. It is true, however, that the magnitude fixes the
multiplexing frequency which might in some circumstances be inconsistent with
other requirements.
    Advantageously, herefore, the computer can be arranged always to first store a
number of sampled values before evaluating them. These stored values can be used
in multifarious ways for interpolation and extrapolation calculations.

In the simplest case, it is possible to provide a possibility of accurate interpolation by a variation of the sampling sequence:

$$U_R - I_R - U_R - U_S - I_S - U_S - U_T - I_T - U_T.$$

In this case, the multiplexer requires no more inputs, i.e. eight inputs including the zero-point and calibration correction, but the number of timing pulses per multiplexer cycle is increased. The computer can then calculate by linear interpolation from the two sampled voltage values on either side of the associated current value in respect of time the missing voltage value and can then multiply the latter by the respective current value for ascertaining the instantaneous power.

A further sampling sequence is:

$$U_R - U_R - I_R - U_S - U_S - I_S - U_T - U_T - I_T$$

from which the computer calculates by extrapolation the voltage value associated in point of time with the current value.

In order to avoid the increase in the number of timing pulses per multiplexer cycle, it is alternatively possible to effect an interpolation which is more extensive in respect of time. In this case, like multiplexer cycles no longer succeed one another, but the three voltages:

$$U_R - U_S - U_T$$

are first alternately sampled, and the three currents:

$$I_R - I_S - I_T$$

are sampled in the next passage through the multiplexer. The computer then interpolates the voltage value associated with the current value in respect of time from the two voltage values which are derived from the preceding and succeeding multiplexer cycles. With a sufficiently high multiplexing frequency, the interpolation error which occurs remains sufficiently small.

In principle, it is immaterial whether the voltage values or the current values are ascertained by interpolation. In the method comprising double sampling of the voltages or of the currents, however, it is desirable to sample the currents more frequently, because the supply system voltage is generally of very good sinusoidal form, while the current may be greatly distorted, for example by thyristor-controlled loads, so that it is more accurately determined by the more frequent sampling.

It is also possible in the interpolation to effect the mean-value formation on the plane of the instantaneous power, that is to say, for example, with the sampling sequence U—I—U the first voltage value may also first be multiplied by the current value, and then the second, and the averaging can be effected by way of the two products.

It is shown in Figure 5 how — without regard to the multiplexing of the three phases — a voltage u(t) and an associated current i(t) are sampled. The number of sampling operations will be denoted by n. The individual sampled values are multiplied by one another as follows:

$$p_{ui}(t) = \frac{1}{n}(u_0 i_1 + i_1 u_2 + u_2 i_3 + \ldots + u_{(n-1)} \cdot i_n).$$

By introducing the functional values, there is generally obtained:

$$P_{ui}(t, \mathcal{Y}) = \frac{1}{n} \left\{ \sum_{\nu=0}^{n/2-1} [\hat{u} \sin(\omega_0 \, \nu \, T_M)] \, [\hat{I} \sin(\omega_0 \nu T_M \cdot \mathcal{Y} \cdot \frac{2\pi}{n})] \right.$$

$$\left. \cdot \sum_{\nu=1}^{n/2} [\hat{u} \sin(\omega_0 \, \nu \, T_M)] \, [\hat{I} \sin(\omega_0 \, \nu \, T_M \cdot \mathcal{Y} - \frac{2\pi}{n})] \right\}$$

The result for the relative measurement error of the power is:

$$f_{rel} = |\cos(\omega_o/f_{M}) - 1|$$

The error is dependent neither upon the drive nor upon the phase displacement between voltage and current, but only upon the number of sampled values per period. The period and the number of sampled values per period, however, are constants; therefore, the measurement error can be included in the calibration once and for all and is thus eliminated. For a measurement error of 1%, at least n=44 samples per period (20 ms) are obtained; this leads to a sampling frequency of 1.1 kHz. It is immaterial whether the sampled values of voltage and current can be acquired in one and the same multiplexer cycle or in alternate multiplexer cycles; the only determining factor for the measurement error is the time spacing.

With alternate cycles, the number of timing pulses in a sampling cycle is reduced to four, the sequence having, for example, the following appearance:

U_R–U_S–zero — I_R–I_S–I_T–reference voltage — U_R–U_S–U_T–zero — I_R–I_S, etc.

Theoretically, it is possible to store intermediately in analog form at the instant of the sampling of one quantity, for example of a voltage, the associated value of the other quantity, for example of a current, so that a pair associated in respect of time is available for the formation of the product. In practice, this is difficult because, in kilowatt-hour meters, the measuring error remains constant in relation to the momentary measured value over the whole measuring range, so that even very small values must be accurately determined. Even the intrusion of switching pulses would falsify considerably the stored values if an analog store were employed.

Since the problems arising with single-channel multiplexing can thus be solved, the principal remaining source of error is the analog-digital convertor, because the subsequent digital further processing by the computer may be regarded as free from error.

In each multiplexer cycle — or, for example, in each second multiplexer cycle in the case of alternate multiplexer cycles — there is contained a zeroising phase in which the input of the analog-digital converter is connected to zero potential by way of the multiplexer. When the analog-digital converter applies to the computer a digital value other than zero, the computer detects the deviation and stores the value, in order thereafter to correct therewith each further digital value supplied by the analog-digital converter, before the evaluation. Owing to the rapid succession of zeroising phases, even relatively rapid zeo-point migrations of the analog-digital converter are eliminated. Consequently, there is no zero-point error at any time in the whole lifetime of the equipment.

In each multiplexer cycle — or in each second one in the case of alternating cycles — the input of the analog-digital converter is applied by way of the multiplexer to a reference voltage whose desired value is contained in the store of the computer. When the analog-digital converter supplies a digital value differing from this desired value, the computer establishes the difference, stores the correcting factor and thereafter corrects each supplied value after having taken into account the zero-point error. In this way, the calibration or pitch error is eliminated throughout the useful life of the appliance.

As residual error, there remains the linearity deviation of the analog-digital convertor conversion curve, but this can always be kept sufficiently small because it depends substantially only upon the precision of the resistance divider network.

Owing to the requirement for constant relative measuring error throughout the measuring range, it is undesirable to operate with a linear analog-digital converter conversion curve which requires a more costly analog-digital converter, the accuracy of which would not be fully utilised in the case of large measured values. Therefore, a non-linearly gradated characteristic curve is preferred, which is of such kind that the relative measurement error is equal at each point of the curve. The logarithmic gradation, which is suitable per se for this purpose, is advantageously replaced by binary gradation, which is easier to apply. Of course, any desired analog-digital converter conversion curve can be taken into account by a suitable program of the computer. All the circuitry parts of the electronic energy meter which have hitherto been referred to — the multiplexer M, the

microcomputer MC and the analog-digital converter AD — can be monolithically integrated, including the resistors of the analog-digital converter.

In the case of a three-phase current meter, there are employed, for example, voltage dividers and current transformers, for example of the type having a ferrite shell-type core, with or without electronic error compensation. The multiplexer and the analog-digital converter may selectively process all input signals in the form of voltages or of currents, it being more readily possible for currents to be passed through the multiplexer; the comparator of the analog-digital convertor also preferably compares currents instead of voltages.

In any case, the six input quantities must be scaled down in order that they may be processed by the electronic system. In the manufacture of such a meter, therefore, the voltage divider ratios and the load resistors at the current transformers, for example, must be adjusted to their desired values. Such adjusting operations require costly adjustable component parts and are particularly labour-intensive.

This disadvantage can be obviated by virtue of the fact that, in principle, all adjusting operations are eliminated, being replaced by corresponding programming in a store. For this purpose, the actual values of the voltage divider ratios, the current transformation ratios (including the load resistances) and the reference voltage are measured in a preferably fully automatic testing operation in each instrument, and corresponding correction values are written into a store accessible to the computer. There is desirably employed for this purpose a programmable read-only store (PROM), which is contained in the computer switching circuit and is automatically programmed by the testing device. If a repeatedly programmable read-only store (RePROM) or electrically alterable read-only store (EAROM) is employed, subsequent recalibrations of the meter can again be effected with the same testing apparatus by programming-in fresh values.

Electronically error-compensated current transformers are known and permit very accurate current transformations with small ferrite shell-type cores. However, owing to the necessary auxiliary amplifier, they generally have at the output an offset unidirectional voltage. In the calculation of the instantaneous power, no error is set up in this way provided that such a unidirectional voltage component is present only at one input of the multiplier; this is a pre-requisite if the meter is fed by voltage and current transformers, as has hitherto usually been the case. In the case of employment with direct connection, however, it is quite possible in the case of relatively long supply lines and thyristor-controlled loads for a unidirectional component of the voltage to be set up which, together with the unidirectional offset of an electronically error-compensated current transformer, would give a measurement error. It is therefore desirable to omit the electronic error compensation. Current transformers having ferrite cores exhibit relatively large errors. When the method described here is applied, the automatic testing device is capable of measuring the two error curves of each individual one of the three current transformers in a meter over the whole control range and to store them in the programmable read-only store (PROM). The computer will then weight each individual measured current value supplied by the analog-digital converter with the associated error curves. A pre-requisite for the practical application of this method is that the error curves of such a current transformer should remain within given tolerances over a relatively long time and even after any possible overloading.

In a further development of the invention, temperature-dependent measurement errors are substantially compensated for in like manner by virtue of the fact that the known and generally only slightly specimen-dependent temperature coefficients of the component elements which are not affected by the automatic zero-point and calibration correction are also stored in the programmable read-only store (PROM), while there is also provided a suitable temperature sensor whose output signal is applied to the computer at sufficient intervals of time by way of the multiplexer and the analog-digital converter. When particular requirements have to be met in regard to measuring accuracy, it is of course also possible to measure automatically in the case of each individual specimen the temperature curve of the reference voltage source which determines the calibration, and to store it in the programmable read-only store (PROM).

When the meter is in service for a long period of time, the ageing-induced drifts of the component elements not affected by the zero-point and calibration correction are of importance. There are principally concerned here the input voltage dividers, the current transformers and the reference voltage source. In well-controlled manufacture, the ageing rates are known and could also be stored

in the non-alterable read-only store (ROM) or programmable read-only store (PROM) of the computer. Since energy meters operate in most cases with a mains supply for the electronic system, there can readily be derived from the mains frequency a time base which is set to zero in the aforesaid fully automatic testing operation. In the calculation of the energy, the computer takes account of the momentary state of the time base and the ageing rates for substantially compensating for influences due to ageing, and, upon re-checking of the meter, new correction values or curves arising from the ageing which has meanwhile occurred in the component elements are written into the respective store.

In the case of an energy meter—more especially a three-phase current meter—the analog-digital converter must process a very large dynamic range. Since its input is continuously changed over to other input quantities by the multiplexer, its input signal may jump from one sampling to the next, for example from the maximum negative value to the maximum positive value. These large signal jumps impose high requirements on the comparator of the analog-digital converter. The comparator requires a particular recovery time after each overshoot. The exact monitoring of a signal value suddenly changing from a maximum value to one close to zero is critical. A known monitoring analog-digital converter avoids this problem in that the comparator input signal corresponds in each instance only to the difference between two samples.

In a further development of the invention, the principle of the monitoring analog-digital converter is also applicable. At each sampling of an input quantity, the sampled value is any case stored, as described, in the computer for the purpose of interpolation. After each sampling, the analog-digital converter converts the analog value into a digital value which is taken up by the computer. Thereafter, the analog-digital converter is again free and can be preset by the computer, before the commencement of the next sampling, to the last sampled value of the input quantity which is now to be sampled. The comparator again receives only the difference between two successive sampled values. The presetting of the analog-digital converter and the application of the input quantity to be measured must be so adapted to one another in respect of time that a comparator overshoot is kept to a minimum.

As already mentioned, it is advantageous to supply the input quantities as currents and to provide a current comparator.

As compared with a conventional Ferraris meter, the measuring method described here is susceptible to disturbing pulses owing to its rapidity. In order to make the electronic energy computer behave similarly to the Ferraris meter, the computer is advantageously so programmed that the jumps between two samplings are limited in their extent and relatively large jumps are evaluated as spurious pulses. In this case, either such sampled values recognised as spurious must be entirely suppressed, or the part which exceeds the programmed maximum value is subtracted. In addition, a sliding mean-value formation is possible. In this case, the averaging takes place before the calculation of the instantaneous power, or even after it.

By appropriate programming of the computer, it can be ensured that the often undesirably accuracy of the measurement is reduced in respect of the determination of harmonics of the mains frequency and made similar to that of a Ferraris meter. For this purpose, Fourier transformation (FFT) is carried out, for example by the computer, advantageously to take into account only a fundamental wave. After the calculation of the instantaneous power of each phase by multiplication, a digital word is available as result, the values of the three phases also having to be added in the case of a three-phase current meter. For determining the energy, an integration over the time is also necessary.

The energy consumption is detected in an accumulator register and displayed on an indicating device. For this purpose, the known counting and storing cyclometer-type registers having step-by-step motor drive may be employed. Alternatively, storing electronic indicating devices, for example electrochromic or electrolytic displays, may be used. Normal non-storing electronic indication is also possible if a non-volatile store, for example a MNOS store, is available, which store is refreshed sufficiently frequently to ensure that data is maintained. Owing to the limited number of write cycles which such a store can perform before becoming unserviceable, the numerical value which must be saved must be written therein in the event of a detected imminent mains failure.

With each kind of digital indication, a jump in the lowest digital position corresponds to a particular amount of consumed energy. These counting pulses

must be obtained, for example, by the computer counting off, after determination
of the whole instantaneous power, a number of periods of a reference frequency
corresponding to this instantaneous power; these counted-off pulses must then be
applied to the display unit either directly or after corresponding frequency division.
Alternatively, it is possible to change over in each instance, with that value of the
instantaneous power which is present as the digital word, a programmable
frequency divider which continuously divides the pulses of the reference frequency
source by the programmed factor. Preferably, the mains frequency is used as the
reference frequency; it is alternatively possible to derive the timing frequency of
the computer from the supply frequency by way of a phase control loop (PLL) or to
use a quartz element. The computer is caused by a corresponding programme to
count off particular times; the programmable timer contained in many computers
may also be used with advantage.

For testing purposes, it is advantageous to employ a particular testing output
of the computer, at which the energy consumption is available with a shorter
measuring time than at the output intended for the indicating device.

Economical computers operate with relatively low timing frequencies and
therefore require long times, for example, for multiplications. In order to save time
in the multiplication, use must again be made of the principle of the monitoring
analog-digital converter, wherein the full values of voltage and current are not
multiplied by one another each time, but only the difference values in relation to
the preceding sampled values, in accordance with the scheme:

$$u_n \cdot i_n = u_{n-1} \cdot \Delta i + i_{n-1} \cdot \Delta u$$

If the multiplication time is too long for such an application in the ease of
serial processing, a separate parallel multiplication unit can always be employed
without any change in the described measuring principle.

A particular problem with electronic energy meters is the safety against
disturbance. Conventional Ferraris meters withstand exceptionally high peak
voltages at the inputs, and they often withstand peaks of more than 10 kV. The
current input proposed as advantageous — even on the voltage side — is also found
to be more favourable in this respect, because practically no voltages arise on the
equipment side, so that very effective protective measures can be applied.

In an energy meter comprising a computer, special precautions must be taken
against penetration of disturbances into the electronic system, because a disturbing
pulse in a computer can lead not only to incorrect data, but also to an incorrect
instruction. In this respect also, we have found that the single-chip microcomputer
proposed in German Patent Application P 2537549.9 has proved superior, because
the effects of disturbances are minimised if the whole computer is integrated on a
single semiconductor crystal. Disturbances then only affect the inputs and outputs
of the computer, disturbances at the inputs merely producing periodically incorrect
input data, but not causing any incorrect performance of the programme.

There is illustrated in Figure 1 the less advantageous, because more costly,
solution comprising a two-channel multiplexer M and two analog-digital converters
AD_1, AD_2. Each multiplexer M has five inputs, since each of the two multiplexer
channels and each of the two analog-digital converters AD_1, AD_2 must be
corrected in regard to their zero-point and calibration errors. A microcomputer
MC controls both the multiplexer M and the analog-digital converters AD_1, AD_2.
For the purpose of energy calculation, it also receives the reference frequency f_{ref}.
The cumulative energy consumption is finally displayed on an indicating device. In
this figure, as in the succeeding figures, it is assumed that the microcomputer MC
also comprises the necessary stores. This applies also to the frequently mentioned
electrically programmable store for receiving the correction curves or values. For
example, there may be employed a metal-nitride-oxide semiconductor store
(MNOS). Of course, it is also possible to assemble the microcomputer MC from a
number of integrated switching circuits; this does not in any way change the idea of
the invention.

Also, it is possible in accordance with the prior art to accommodate the
analog-digital converter or converters AD_1, AD_2 together with the associated
resistors, as well as the multiplexer or multiplexers M, together with the computer
on a single switching circuit. The whole electronic cie-chain integrated circuit then
consists substantially of three current transformers, one resistance arrangement
(for example thin-film or thick-film technique), the major switching circuit, the

display means and the current supply system. As described, it does not comprise any component elements that can be balanced or adjusted.

There is illustrated in Figure 2 the more advantageous solution comprising a signal-channel multiplexer M and only one analog-digital converter AD, wherein all the input signals of the multiplexer M are present in the form of voltages. The illustrated sequence of the connections is not essentially identical with the sequence in which the input signals from the multiplexer M are sampled. The computer passes the address of the desired input in each instance through a control line to the multiplexer M; the sequence is dependent upon the programme chosen.

There is illustrated in Figure 3 the circuit arrangement in the case where all the input signals of the multiplexer M are present in the form of current signals.

There are shown in Figure 4 different possible ways of sampling the signals and calculating the instantaneous power in each phase, Figures $4a$, $4b$ and $4c$ here relate to the measurement of only one phase, while Figures $4d$, $4e$ and $4f$ apply to the measurement in the case of three phases.

The invention is also applicable with any desired number of phases, for example even to a so-called three-conductor meter, in which only two measuring channels are required.

Figure $4a$ illustrates the sampling and the interpolation in the case of the voltage and current measurement in a single-phase system: the indices denote the number of the respective sampling; the voltage and current inputs are alternately sampled. A first sub-product (instantaneous power) p_1 is obtained, for example, by interpolating from the two voltage samples u_0 and u_2 a voltage value which is thereafter multiplied by the sampled current value i_1. A further sub-product p_3 is obtained, for example, by interpolating from the two voltage values u_2 and u_4 a value which is thereafter multiplied by the current value i_3. The total power P is obtained for a particular number of samples n as:

$$P = \frac{2}{n}(p_1 + p_3 + \ldots),$$

in which

$$\frac{n}{2}$$

multiplications are performed.

Voltages and currents are completely equivalent and can thus be interchanged.

In Figure $4b$, there is illustrated another product formation for the same case of alternate sampling of input voltage and input current: sub-products p_n are here formed from the sampled values present, the voltage and the current being alternately interpolated. The power P is here calculated as:

$$P = \frac{1}{n}(p_1 + p_2 + p_3 + \ldots)$$

There is illustrated in Figure $4c$ an example of the case where the averaging takes place only after the formation of the sub-products p_n. The total power P is obtained as in case $4b$, but only one store is here required for any one sampled value, because no interpolation takes place, or no mean value is formed, before the multiplication.

The following applies to all three methods:

$$p = \frac{1}{n}(u_0 i_1 + i_1 u_2 + u_2 i_3 + i_3 u_4 + \ldots)$$

For that part of the measurement which is of greatest practical importance in a three-phase current supply system, the sampling of the phase R is first shown in Figure $4d$, the sampling of the phase S in Figure $4e$ and the sampling of the phase T in Figure $4f$. The following sampling sequence has here been assumed:

$$U_R - I_S - U_T - I_R - U_S - I_T.$$

The arrows shown with the sub-products p_n indicated how these sub-products have arisen.

A large number of sampling frequencies is possible; some typical ones for the method of the invention are, for example:

$$U_R-I_R-U_R-U_S-I_S-U_S-U_T-I_T-U_T$$

$$U_R-I_R-U_R-I_S-U_S-I_S-U_T-I_T-U_T-I_R-U_R-I_R-U_S-I_S-U_S-I_T-U_T-I_T$$

$$U_R-U_S-U_T-I_R-I_S-I_T$$

$$U_R-I_S-U_T-I_R-U_S-I_T$$

As mentioned, the computer determines which input signal the multiplexer M is to pass in each instance, so that, depending upon the programme, any desired sampling sequences and any kind of evaluation of the samples are possible in the same circuit arrangement.

In the case of the energy meter comprising a computer as described here, the sampling according to Figure 4a is particularly desirable, because a computer can relatively rapidly add, but takes a comparatively very long time for a multiplication; according to Figure 4a, however, only $n/2$ multiplications are carried out.

In Figures 4a to 4f, the sampling of the zero-point or reference potential has been omitted for the sake of clarity. Depending upon the drift to be expected in the zero point or the calibration, it is merely necessary that the zero-point or calibration potential should be sampled at sufficient intervals of time and that corresponding correction values should be formed and stored. It is therefore by no means necessary for the aforesaid other two quantities to be simultaneously sensed in each cycle for the sampling of the input quantities.

In the above described meters, in the determination of the deviations of those component elements which enter the measurement results from desired values, the multiplexer and the analog-digital converter may be employed simultaneously. Then, suitable input signals are applied to the meter and actual values are taken from the output of the analog digital converter or from a suitable output of the computer in digital form, so that all the curves or correction values thus measured contain the individual deviations both of the multiplexer and of the analog-digital converter from the desired conversion characteristic curve and of the analog-digital converter from the desired conversion characteristic curve between 0% and 100% of the measurement range, whereby, with an appropriate number of measuring points per correction curve, each deviation of the conversion characteristic curve from its desired form (linear, logarithmic, binary, etc) is compensated to within any desired small residual error.

The multiplexing frequency of the above described meters may be synchronized with mains frequency, or it may free wheel in relation to mains frequency or be additionally frequency modulated. Alternatively, the multiplexing frequency may be derived from a timing frequency of the computer by way of a program thereof. A time setting required for carrying out integration operations, may be produced in a manner known per se by a program loop or a timer included in the computer, where a timing frequency of the computer is used as a reference frequency.

The above described meters may be arranged to operate as maximum demand meters, or as excess consumption meters. Their output signals may represent, in addition to energy consumption, a reference frequency, a meter test, or a meter identification code. An electrically programmable store of the meter may contain a meter identification which consists of a serial number and optionally a data code and a test code. The meters may be provided with a protected connection for a testing instrument, with the aid of which the meter can be tested. The meters may be arranged to perform metering operations other than simple energy computation. For example, in a meter, the computer may be programmed to receive instructions from a centralised control, and be so programmed that it effects by digital filtering methods, not only decoding of the centralised control instructions, but also the filtering out of centralised control pulses after appropriate level matching and signal processing. Then, programming of the computer as a centralised control receiver may be contained in a non-volatile store. In the performance of tasks of a centralised-control receiver, the computer may output control signals particular to a respective energy consumer.

WHAT WE CLAIM IS:—

1. An electrical energy meter for metering an a.c. supply having one or more phases, the meter having a solid-state measuring unit which comprises:

a multiplexer having inputs for receiving current- and voltage-proportional signals for the or each phase, a zero potential signal, and a reference potential signal, and arranged to output said signals successively;

an analog-digital converter connected to receive the multiplexer output and arranged to output the same in digital form; and

a digital computer arranged to control operation of the multiplexer, to receive the output of the converter, and to perform the following operations:

calculation and storage of a zero-point error value from the zero-potential signal when received by the computer;

calculation and storage of a calibration error value from the reference potential signal when received by the computer;

compensation of each received said current- and voltage-proportional signal for said error values;

for the or each phase, storage of a succession of values of at least one of said current- and voltage-proportional signals for that phase, as successively sampled by the multiplexer, and interpolation within or extrapolation from said succession of values to compensate for relative time displacement between sampling instants of the current- and voltage-proportional signals;

for the or each phase, calculating from the error value compensated current- and voltage-proportional signals the instantaneous power for that phase; and

providing an output signal representative of energy consumption from said supply.

2. A meter according to claim 1, for metering a single-phase supply.

3. A meter according to claim 1, for metering a polyphase supply, wherein the computer is arranged to sum the instantaneous powers of the respective phases.

4. A meter according to claim 3, for use in metering a three-phase supply.

5. A meter according to claim 4, wherein said multiplexer is a single-channel multiplexer having eight inputs, three of which are for receiving the phase current-proportional signals, another three of which are for receiving the phase voltage-proportional signals, and the remaining two of which are for receiving said zero potential and reference potential signals.

6. A meter according to any one of the preceding claims, including indicator means for indicating said energy consumption.

7. A meter according to claim 6, wherein said indicator means has a non-volatile store associated therewith.

8. A meter according to any one of the preceding claims, wherein said interpolation or extrapolation is linear.

9. A meter according to any one of the preceding claims, wherein the computer is arranged to effect said time displacement compensation before the calculation of the phase instantaneous power(s).

10. A meter according to any one of claims 1 to 8, wherein the computer is arranged to effect said time displacement compensation after the calculation of the phase instantaneous power(s).

11. A meter according to any one of the preceding claims, wherein said output signal includes a reference frequency.

12. A meter according to any one of the preceding claims, wherein the deviations of the actual values from the desired values of those parts of the meter which are not affected by compensation for said zero-point and calibration error values and of a source of said reference potential are determined and corresponding correction values are stored in an electrically programmable store and taken into account by the computer in the calculation of the energy consumption.

13. A meter according to any one of the preceding claims, wherein a timing frequency of the computer is derived from a quartz element or by way of a phase control loop from the mains frequency.

14. A meter according to claim 13, wherein the timing frequency of the computer is used as a reference frequency for integration operation by the computer.

15. A meter according to any one of the preceding claims, wherein the multiplexing frequency is synchronised with the mains frequency.

16. A meter according to any one of claims 1 to 14, wherein the multiplexing

frequency freewheels in relation to the mains frequency or is additionally frequency-modulated.

17. A meter according to any one of claims 1 to 14, wherein the multiplexing frequency is derived from the timing frequency of the computer by way of a program thereof.

18. A meter according to claim 4 or to any one of claims 5 to 17 as appendant thereto, wherein said multiplexer is a two-channel multiplexer each channel having five inputs, and is arranged to feed two said analog-digital converters, wherein one of each set of five inputs is for receiving said zero potential signal, a second one of each set of five inputs is for receiving said reference potential signal, the phase voltage-proportional signals are applied, in use, to the remaining three inputs of one set, and the phase current-proportional signals are applied, in use, to the remaining three inputs of the other set.

19. A meter according to any one of the preceding claims, wherein, for carrying out integration of instantaneous power values by program control, the computer is arranged to count off a number of periods of a reference frequency, corresponding to the respective instantaneous power value, and apply them to a storage device.

20. A meter according to any one of the preceding claims, wherein, in use, instantaneous power values calculated by the computer are used to set a programmable frequency divider or multiplexer, which divides or multiplies pulses of a reference frequency, and in that the counting pulses thus obtained are applied to a storage device.

21. A meter according to any one of the preceding claims, wherein a timing frequency of the computer is used as a reference frequency, and in that a time setting required for integration operations is produced in a manner known *per se* by a program loop or a timer included in the computer.

22. A meter according to any one of the preceding claims, including means for compensating for time delay in sampling the values of voltage- and current-proportional signals of each phase, by means of an analog delay element.

23. A meter according to claim 2, or to any one of claims 6 to 17 and 19 to 22, as appendant thereto, wherein the multiplexer is a single-channel multiplexer and the computer is arranged to receive sampled values of said current- and voltage-proportional signals alternately and to always store the two values last sampled, and to calculate, at each sampling, from the value just sampled and from the earlier sampled value of the same quantity which is available in the store, an interpolated value, and to multiply the latter value by the value of the other quantity available in the store, thereby to determine the instantaneous power, whereby interpolation values for the voltage- and current-proportional signals are alternately calculated and multiplied by the last stored value of the other quantity.

24. A meter according to claim 2, or to any one of claims 6 to 17 and 19 to 22, as appendant thereto, the multiplexer is a single-channel multiplexer and the computer is arranged to receive sampled values of said current- and voltage-proportional signals alternately and to calculate the mean value from two successive sampled values of one quantity in each instance by interpolation and multiply this means value in each instance by that sampled value of the other quantity which exists in the time interval between them.

25. A meter according to claim 2, or to any one of claims 6 to 17 and 19 to 22, as appendant thereto, wherein the multiplexer is a single-channel multiplexer and the computer is arranged to receive sampled values of said current- and voltage-proportional signals alternately and to continuously multiply by one another in each instance two sampled values of the two quantities which succeed one another in time, and sum the sub-products.

26. A meter according to claim 4 or to any one of claims 5 to 17 and 19 to 22, as appendant thereto, wherein the multiplexer is a single-channel multiplexer which is arranged to sample the current-proportional signals (I_R, I_S, I_T) and the voltage-proportional (U_R, U_S, U_T) signals in the order:

$$U_R–I_R–U_R–U_S–I_S–U_S–U_T–I_T–U_T$$

27. A meter according to claim 4 or to any one of claims 5 to 17 and 19 to 22, as appendant thereto, wherein the multiplexer is a single-channel multiplexer which is arranged to sample the current-proportional signals (I_R, I_S, I_T) and voltage-proportional (U_R, U_S, U_T) in the order:

$$U_R-I_r-U_R-I_S-U_S-I_S-U_T-I_T-U_T-I_R-U_R-I_R-U_S-I_S-U_S-I_T-U_T-I_T$$

28. A meter according to claim 4 or to any one of claims 5 to 17 and 19 to 22, as appendant thereto, wherein the multiplexer is a single-channel multiplexer which is arranged to sample the current-proportional signals (I_R, I_S, I_T) and voltage-proportional signals (U_R, U_S, U_T) in the order:

$$U_R-U_S-U_T-I_R-I_S-I_T$$

29. A meter according to claim 4 or to any one of claims 5 to 17 and 19 to 22, as appendant thereto, wherein the multiplexer is a single-channel multiplexer which is arranged to sample the current-proportional signals (I_R, I_S, I_T) and voltage-proportional signals (U_R, U_S, U_T) in the order:

$$U_R-I_S-U_T-I_R-U_S-I_T$$

30. A meter according to any one of the preceding claims, including means for supplying all input signals to the or each analog-digital converter in the form of voltages.

31. A meter according to any one of claims 1 to 29, including means for supplying all in out signals to the or each analog-digital converter in the form of currents.

32. A meter according to any one of the preceding claims, wherein the conversion characteristic curve of the or each analog-digital converter is so gradated that any measuring error in relation to any given measured value remains constant independently of the measured value, the computer taking into account the conversion characteristic curve of the analog-digital converter in processing the values supplied by the latter.

33. A meter according to any one of the preceding claims, wherein the or each analog-digital converter has a logarithmically gradated conversion characteristic curve the computer taking this curve into account in processing the values supplied by the analog-digital converter.

34. A meter according to any one of claims 1 to 32, wherein the or each analog-digital converter has a conversion characteristic curve gradated in binary form, the computer taking this characteristic curve into account in processing of the values supplied by the analog-digital converter.

35. A meter according to any one of the preceding claims, wherein the or each analog-digital converter is arranged to be controlled by the computer as a monitoring analog-digital converter in which, before sampling a particular quantity, the analog-digital converter is set by the computer to the previous sampled value of the same quantity, so that a comparator of the analog-digital converter only has to process the difference between the new and old sampled values.

36. A meter according to claim 35, wherein, in the calculation of phase instantaneous power, the computer does not multiply the most recently sampled value but only the previous stores value of voltage and current by the current and voltage difference respectively.

37. A meter according to any one of the preceding claims, wherein a parallel multiplication unit is employed for calculating phase instantaneous power.

38. A meter according to any one of the preceding claims, wherein the or each analog-digital converter, and the computer are integrated together on a single semiconductor chip.

39. A meter according to claim 38, wherein the multiplexer is included on the chip.

40. A meter according to any preceding claim, wherein electronically error-compensated current transformers are employed as input stages to the meter and the computer is so programmed that, in the calculation of instantaneous power, it eliminates from the values supplied by the analog-digital converter an erroneous offset unidirectional component which is contained therein and which emanates from auxiliary amplifiers of the current transformers.

41. A meter according to any one of the preceding claims, wherein the computer is so programmed that, in the case of distorted input signals, it only takes into account the fundamental wave in each instance in the calculation of instantaneous power.

42. A meter according to claim 41, wherein, for the purpose of computing the

fundamental wave in the case of a distorted input signal, the computer carries out a Fourier transformation.

43. A meter according to any one of the preceding claims, wherein the computer is so programmed that it assesses as disturbances jumps in the sampled values which exceed a predetermined level, and that it either subtracts the excess part of or rejects such disturbed sampled values.

44. A meter according to any one of the preceding claims, wherein the computer is so programmed that it effects a sliding mean-value operation in the calculation of instantaneous power or of the energy.

45. A meter according to any one of the preceding claims, including an electrically programmable store the content of which can be maintained in the event of a power failure.

46. A meter according to any one of the preceding claims, including an electrically programmable non-volatile store which is arranged to be refreshed at intervals sufficient to ensure that data store therein is maintained.

47. A meter according to claim 7 or to any dependent claim thereof, wherein the existing energy consumption reading is arranged to be stored in the non-volatile store associated with said indicator means, in the event of a power failure.

48. A meter according to claim 6 or to any dependent claim thereof, wherein said indicator means comprises an electronic indicating device.

49. A meter according to any one of the preceding claims, provided with a protected connection for a testing instrument, with the aid of which the meter can be tested.

50. A meter according to any one of the preceding claims, arranged to provide an output signal which is representative of energy consumption and includes a meter identification code.

51. A meter according to any one of the preceding claims, arranged to provide an output signal which is representative of energy consumption and includes a meter test.

52. A meter according to any one of the preceding claims, arranged to perform metering operations other than simple energy computation.

53. A meter according to claim 52, arranged to operate as a maximum demand meter.

54. A meter according to claim 52 or 53, arranged to operate as an excess demand meter.

55. A meter according to claim 52, 53, or 54, wherein the computer is programmed to receive instructions from a centralised-control, and it is so programmed that it effects by digital filtering methods, not only decoding of the centralised-control instructions, but also the filtering-out of centralised-control pulses after appropriate level matching and signal processing.

56. A meter according to claim 55, wherein the programming of the computer as a centralised-control receiver is contained in a non-volatile store.

57. A meter according to claim 55 or 56, wherein the computer, in the performance of the tasks of a centralised-control receiver, outputs control signals particular to a respective energy consumer.

58. A meter according to any one of the preceding claims, comprising a store which is electrically programmable and re-programmable as often as desired and which contains correction values or correction curves for all component elements of the meter which are not affected by the automatic zero-point and calibration correction, but of which the properties or values enter into the measurement, the computer being so programmed that it takes into account in the calculation of energy consumption the respective correction values or curves.

59. A meter according to claim 58, wherein, in the determination of the deviations of those component elements which enter the measurement result from the desired values, the multiplexer and the analog-digital converter are simultaneously employed, suitable input signals being applied to the meter and the actual values being taken from the output of the analog-digital converter or from a suitable output of the computer in digital form, so that all the curves or correction values thus measured contain the individual deviations both of the multiplexer and of the analog-digital converter from the desired conversion characteristic curve between 0% and 100% of the measurement range, whereby, with an appropriate number of measuring points per correction curve, each deviation of the conversion characteristic curve from its desired form (linear, logarithmic, binary, etc) is compensated to within any desired small residual error.

60. A meter according to claim 58 or 59, comprising current transformers for

each of which a correction curve for the magnitude and a correction curve for the error angle are ascertained, stored and taken into acount in computation by the computer.

61. A meter according to any one of the preceding claims wherein generic or individual temperature coefficients or temperature curves of component elements which enter the measurement result are stored in a read-only store (ROM) or in a programmable read-only store (PROM) or in an electrically alterable read-only store (EAROM) of the meter, the meter comprising a temperature sensor, the output signal of which is applied to the computer, and the computer takes into account in the computation of energy consumption the measured operating temperature and the stored temperature dependencies.

62. A meter according to any one of the preceding claims, wherein generic or individual ageing rates of component elements which enter the measurement result are stored in a read-only store (ROM) or in a programmable read-only store (PROM) or in an electrically alterable read-only store (EAROM) of the meter, the meter has a freewheeling time base or a time base derived from a reference frequency, and the computer takes into account the computation of the energy consumption the ageing rates and the existing state of the time base.

63. A meter according to claim 62, wherein the computer is so programmed that, on re-checking of the meter, new correction values or curves arising from the ageing which has meanwhile occurred in the component elements are written into a respective store.

64. A meter according to any one of the preceding claims, wherein an electrically programmable store of the meter contains a meter identification which consists of a serial number and optionally a data code and a test code.

65. A meter according to any one of the preceding claims, being a kilowatt-hour meter.

66. An electrical energy meter substantially as hereinbefore described with reference to Figure 2 or 3 of the accompanying drawings.

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5 SHEETS   This drawing is a reproduction of
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Sheet 1

U_{Ref}

U_R

U_S

U_T

U_{Ref}

$U{\sim}I_R$

$U{\sim}I_S$

$U{\sim}I_T$

M

f_{Ref}

IM

M

M

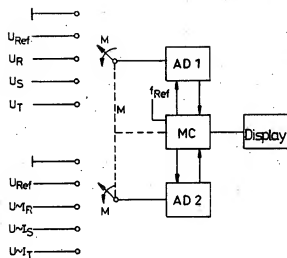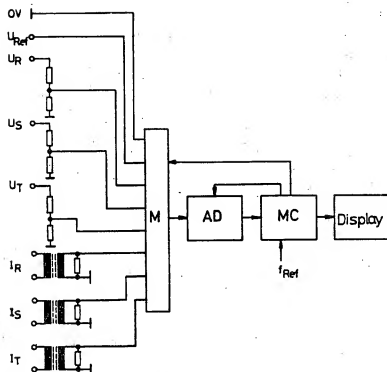AD 1

MC

Display

AD 2

Fig. 1

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Fig. 2

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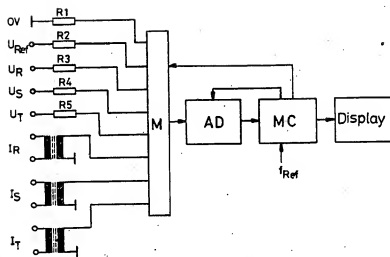the Original on a reduced scale
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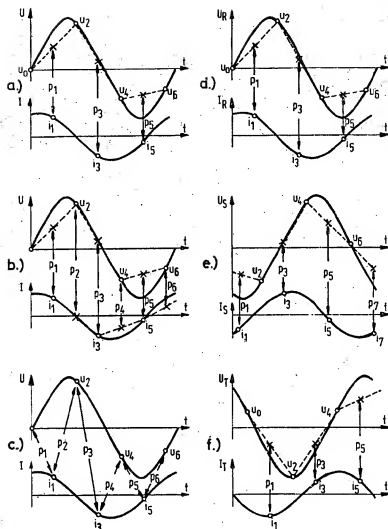
Fig. 3

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Fig. 4

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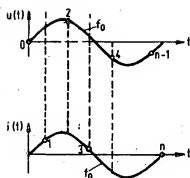   the Original on a reduced scale
                    Sheet 5

Fig. 5